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WFIRST Coronagraph Status

Feng Zhao, CGI Instrument Manager
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Ilya Poberezhskiy, CGI Instrument Systems Engineer
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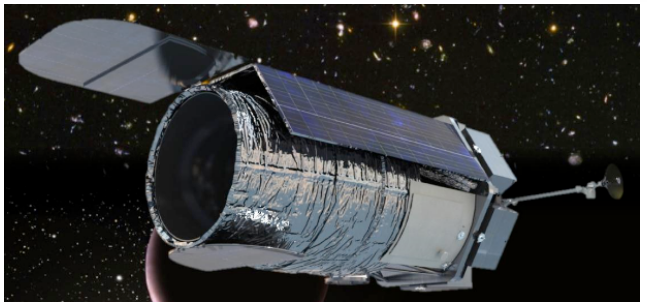
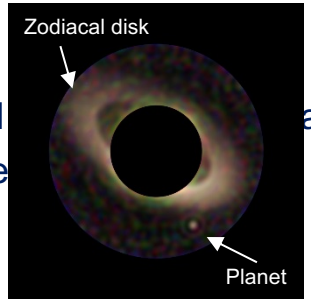
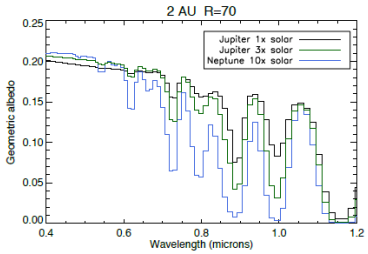
WFIRST Coronagraph Instrument (CGI)

- **Coronagraph (CGI) is the 2nd instrument on WFIRST,**
  - Exo-planet direct imaging technology demonstration
  - Precursor science for future exo-earth missions
- **CGI has two science cameras:**
  - Imaging camera
  - Integral field spectrograph (IFS)
- **CGI advances a number of new technologies:**
  - Novel coronagraph masks (shaped pupil coronagraph and
  - Precision wavefront sensing and control with 2 deformable
  - Ultra-low noise detector

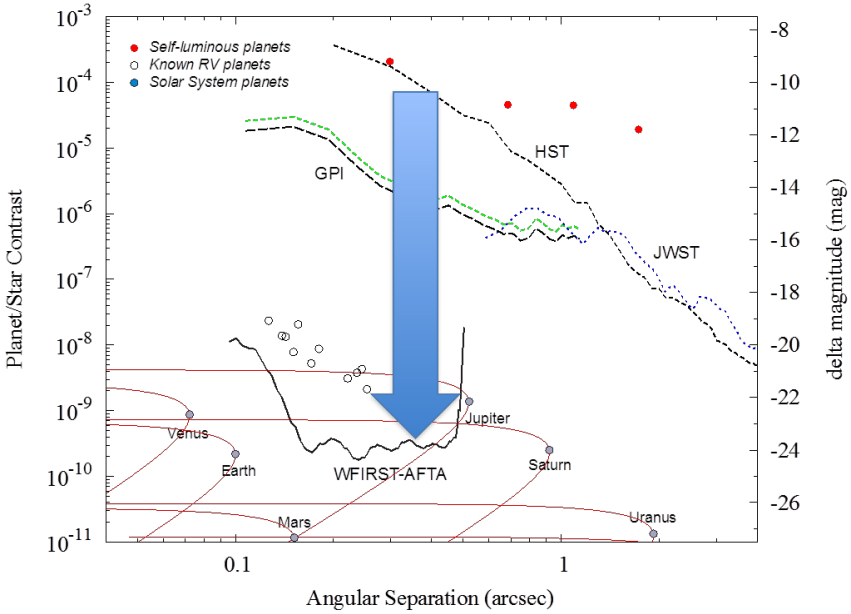


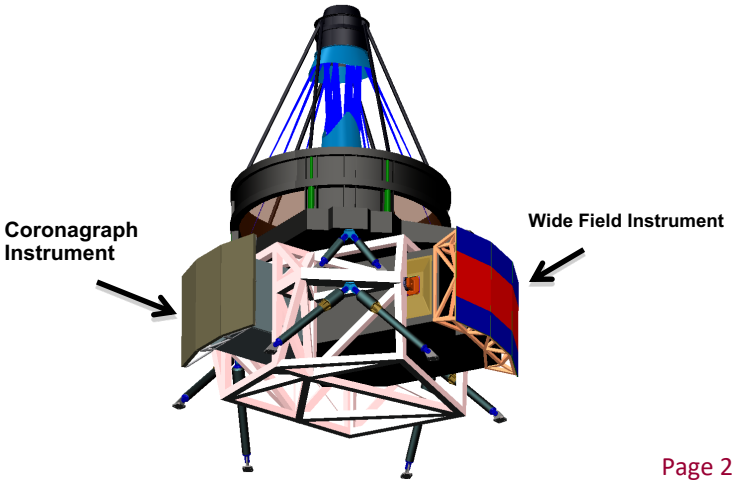




Exo-planet Direct imaging

Exo-planet Spectroscopy





WFIRST Coronagraph Organization and Key Members

- WFIRST is managed by GSFC
  - WFIRST project manager: Kevin Grady
  - WFIRST Project Scientist: Neil Gehrels
- Coronagraph instrument is managed by JPL
  - JPL WFIRST Project Manager: Phil Barela (7060)
  - JPL WFIRST Project Scientist: Wes Traub (3200)
  - Instrument Manager: Feng Zhao (3830)
  - Deputy Instrument Manager: Rick Demers (383D)
  - Instrument Systems Engineer: Ilya Poberezhskiy (383H)
- Current coronagraph partner institutions:
  - NASA centers:
    - GSFC (responsible for integral field spectrograph)
    - ARC (supporting backup technology PIAA-CMC)
  - Industry:
    - Northrup Grumman Xinetics (deformable mirror)
    - e2v (Electron Multiplying CCD – EMCCD)
  - Science Investigations Teams (SIT):
    - SIT #1 PI: Bruce Macintosh, Stanford University
    - SIT #2 PI: Maggie Turnbull, SETI Institute
  - Coronagraph Adjutant Scientist (CAS):
    - Jeremy Kasdin, Princeton University
  - Science Center:
    - IPAC/Caltech, STScI
  - Potential International Partners:
    - Germany -- Max Planck Institute of Astronomy (mask filter wheels)
    - ESA/UK – Open University (EMCCD)
    - Japan – JAXA (polarization module)
    - Canada – CSA/Nuvu/UdeM (EMCCD electronics, IFS)

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Goddard SPACE FLIGHT CENTER

Ames Research Center

PRINCETON UNIVERSITY

THE UNIVERSITY OF ARIZONA.

ipac

SPACE TELESCOPE SCIENCE INSTITUTE

Stanford University

SETI INSTITUTE

e2v centre for electronic imaging

e2v Bringing life to technology

NORTHROP GRUMMAN

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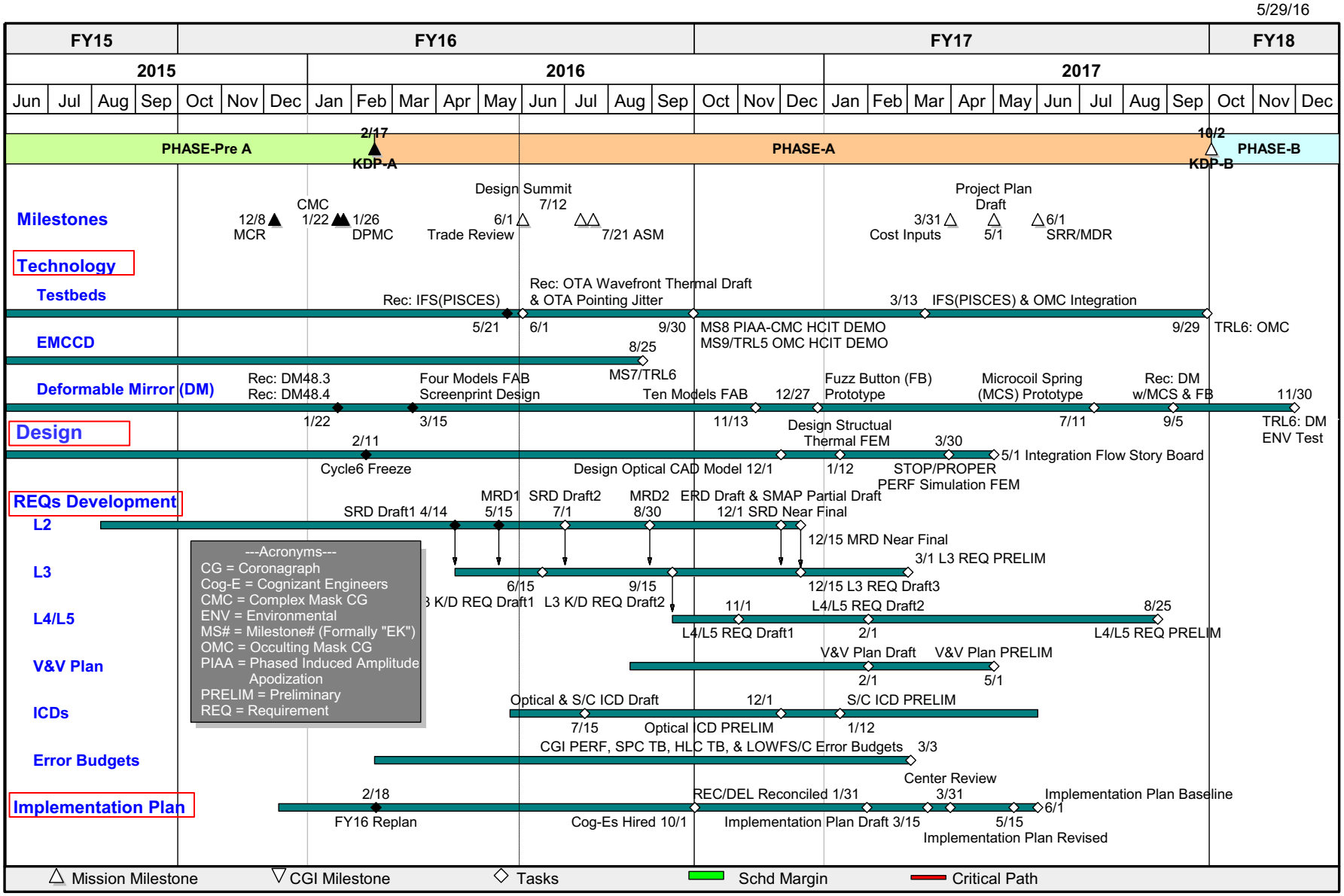
CGI Phase A Schedule and Key Activities



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Coronagraph Technology Development Sequence

12/2013

Coronagraph designs that work with AFTA telescope developed, validated by modeling

12/2014

Fabrication of novel coronagraph components: masks and apodizers demonstrated

2/2015

Narrowband coronagraph contrast demonstration in the testbeds

9/2015

Broadband coronagraph contrast demonstration in the testbeds

Broadband coronagraph contrast demonstration in the testbed with representative optical wavefront disturbances (TRL 5)

TRL 6 demonstration in critical environment

Each milestone is a necessary precondition for the following ones

Reports available in: http://wfirst.gsfc.nasa.gov/library.html

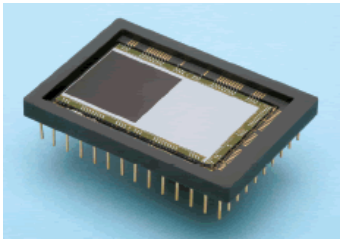
Milestones Tracking WFIRST Coronagraph TRL-5 Progress

MS #	Milestone	Date
1	First-generation reflective Shaped Pupil apodizing mask has been fabricated with black silicon specular reflectivity of less than 10^{-4} and 20 μm pixel size.	7/21/14 DONE
2	Shaped Pupil Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with narrowband light at 550 nm in a static environment.	9/30/14 DONE
3	First-generation PIAACMC focal plane phase mask with at least 12 concentric rings has been fabricated and characterized; results are consistent with model predictions of 10^{-8} raw contrast with 10% broadband light centered at 550 nm.	12/15/14 DONE
4	Hybrid Lyot Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with narrowband light at 550 nm in a static environment.	2/28/15 DONE
5	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a static environment.	9/15/15 DONE
6	Low Order Wavefront Sensing and Control subsystem provides pointing jitter sensing better than 0.4 mas and meets pointing and low order wavefront drift control requirements.	9/30/15 DONE
7	Spectrograph detector and read-out electronics are demonstrated to have dark current less than 0.001 e/pix/s and read noise less than 1 e/pix/frame.	8/25/16
8	PIAACMC coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a static environment; contrast sensitivity to pointing and focus is characterized.	9/30/16
9	Occulting Mask Coronagraph in the High Contrast Imaging Testbed demonstrates 10^{-8} raw contrast with 10% broadband light centered at 550 nm in a simulated dynamic environment.	9/30/16

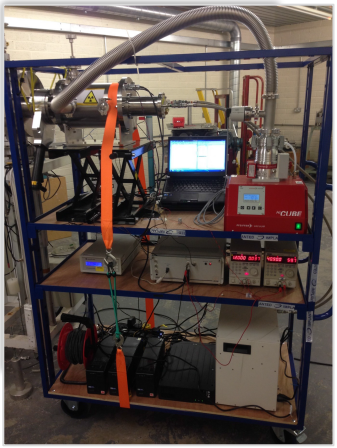
Technology Milestone #7 -- Low Noise Detector

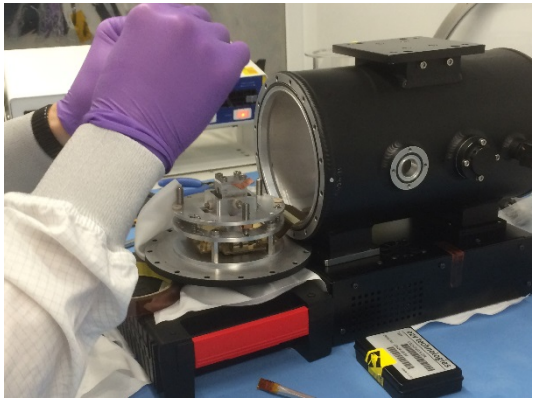
- e2v Electron Multiplying CCD (EMCCD) is base-lined for WFIRST Coronagraph
- Performance at beginning of life (BOL) meets requirements. Technology development focuses on environmental effects (radiation) and mitigations

- **Radiation tests**
  - Test report of cryo-radiation testing campaign completed
    - Conventional CCD performance parameters nearly pass EOL requirements, easily mitigated by beefier shielding design
    - Irradiation at room temperature for unbiased operation resulted in lower performance degradation than at cryogenic temperature under bias at an equivalent exposure
    - Effects of room temperature anneal are favorable for dark current and low flux CTI
- **Evaluation of radiation induced effects:**
  - Lab testing underway: compare damaged and undamaged detectors with an optical scene generator
  - Physics based models to simulate radiation induced defects and their impact to coronagraph performance
  - To compare with lab results above for model validation
- **On track for 8/25/2016 report to TAC**

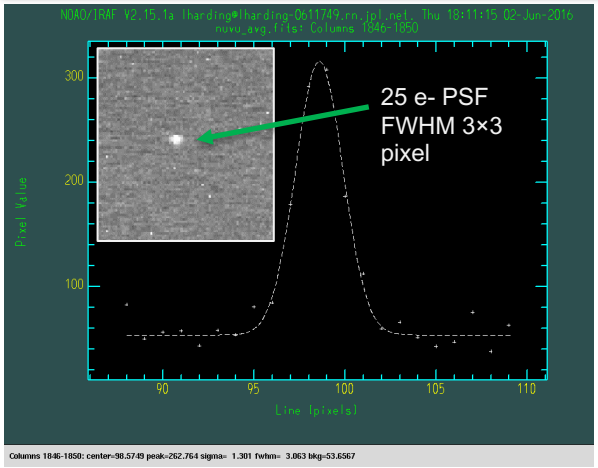


e2v CCD201-20
Electron Multiplying CCD
(1K×1K format)





Rad-exposed EMCCD: 2.5×10^9 pr/cm^2



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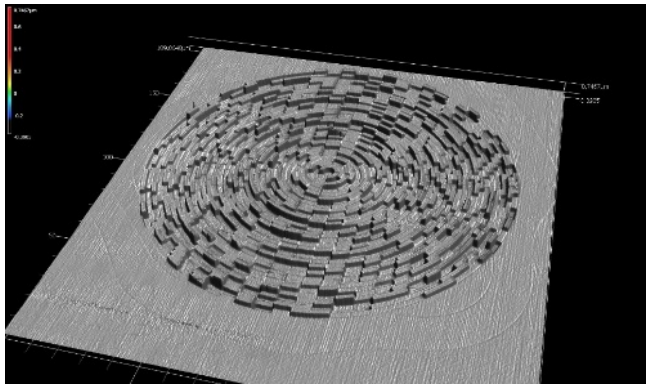
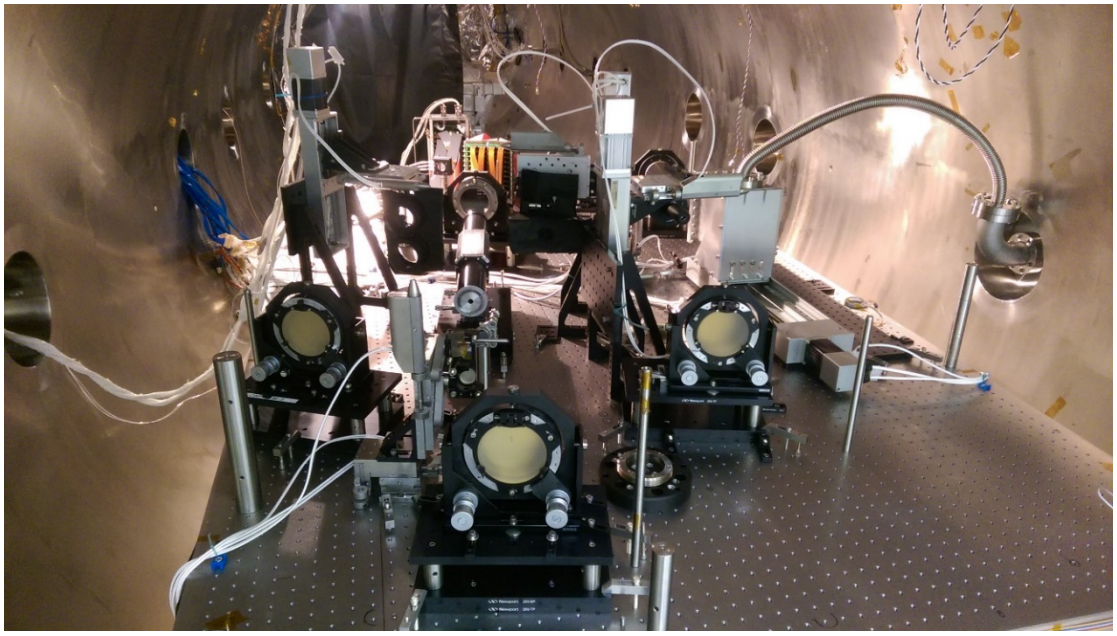
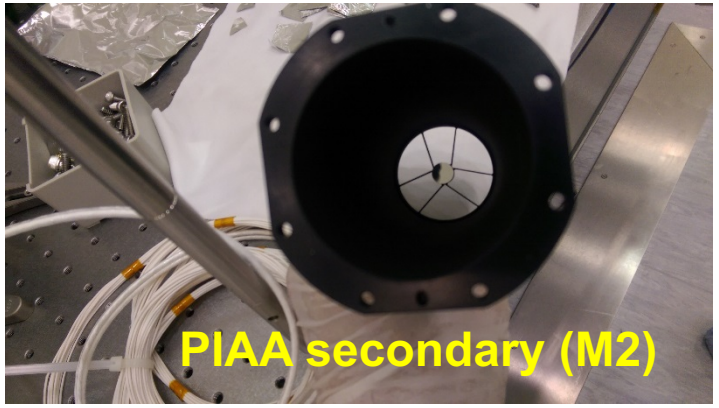
Technology Milestone #8 – PIAA-CMC Testbed

- **Back-up coronagraph technology: Phase Induced Amplitude Apodization Complex Mask Coronagraph (PIAA-CMC)**
  - On-axis PIAACMC M1/M2 telescope assembly from Nu-Tek/Welch;
- **PIAACMC testbed commissioned, and started vacuum nulling runs.**
- **On track for 9/30/2016 PIAA testbed demonstration (static)**



PIAACMC mask image with a laser confocal microscope





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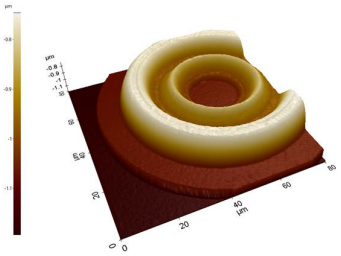
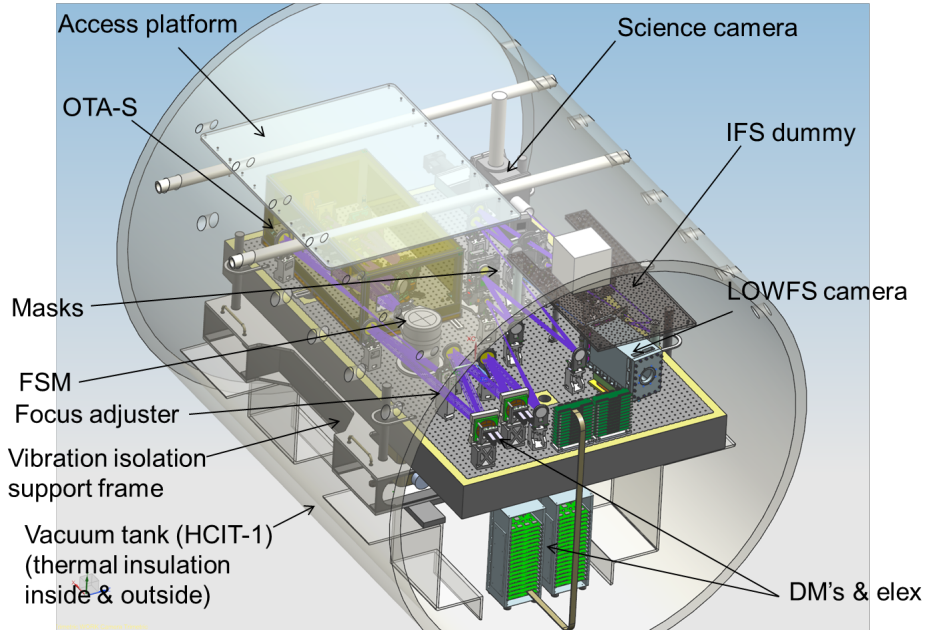
Technology Milestone #9 – TRL 5 Testbed Demonstration

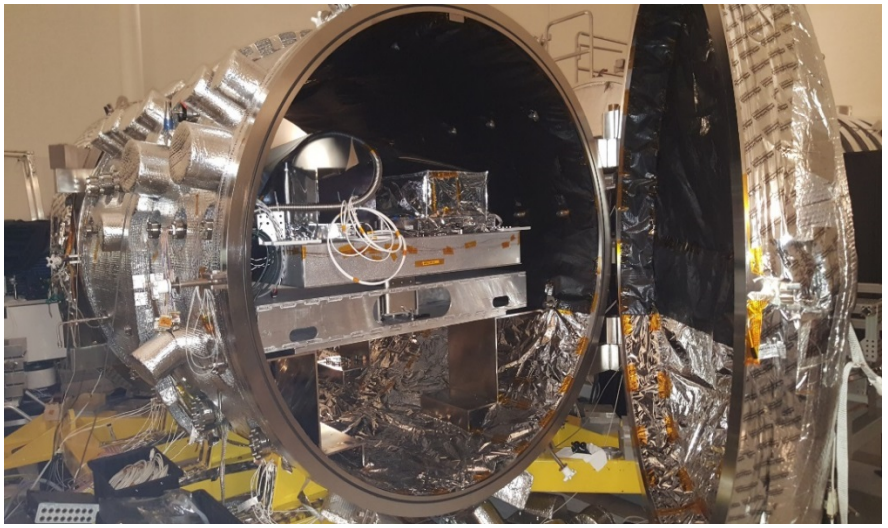
- **Primary coronagraph architecture was chosen in 2013 by AFTA Coronagraph Working Group (ACWG)**
  - Hybrid Lyot Coronagraph (HLC) mode
  - Shaped-pupil Coronagraph (SPC) mode
- **TRL-5/6 coronagraph testbed optical layout builds on same OMC architecture and with same prescription (48X48DM, shaped-pupil mask, occulting masks, Lyot stops, field-of-view, pixel scale, optical coatings, etc.) on a bread-board optical bench that can be modeled for performance validation**
- **OMC testbed operating in HCIT1 vacuum chamber, started nulling runs**
- **On track for 9/30/2016 testbed demonstration (dynamic environment)**

SPC mask



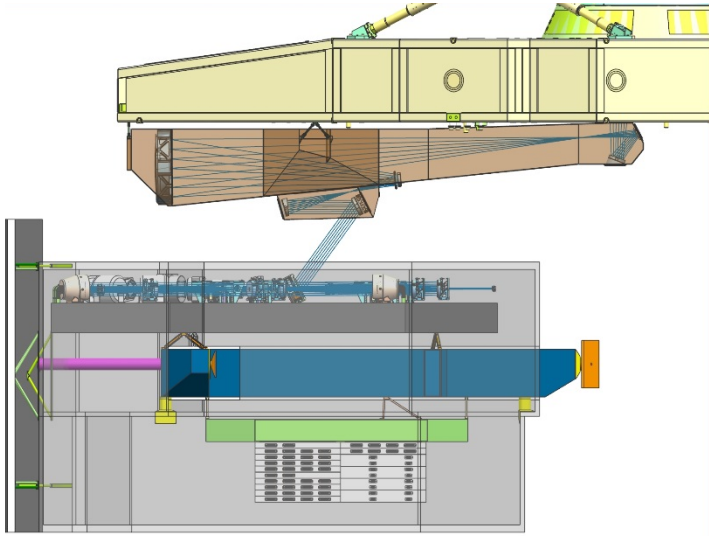
HLC mask

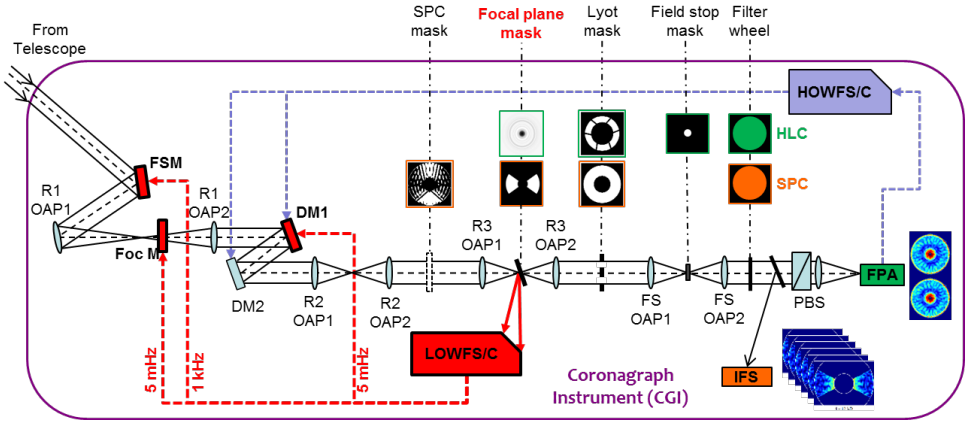


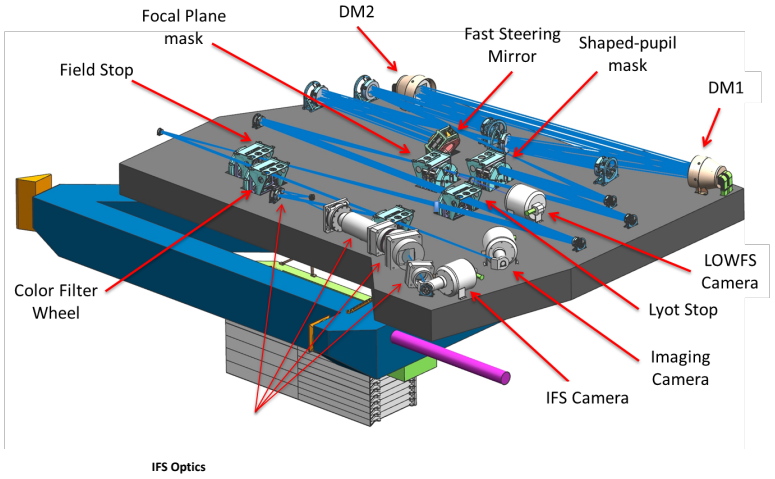


WFIRST Coronagraph Instrument Design

- Primary coronagraph architecture: Occulting Mask Coronagraph = Shaped Pupil + Hybrid Lyot
  - SP and HL share same optical layout
  - Operate with different apodizing and occulting masks
- No major changes from MCR design
- Currently focusing on requirement flow-down and engineering trades:
  - FLT LOWFS camera
  - FLT electronics and software architecture
  - Pointing control architecture
- Simulations:
  - Working to produce a pipe line/libraries for SIT simulations
  - Updated instrument parameters in IPAC website
  - More details during Day #2 CGI Breakout Session







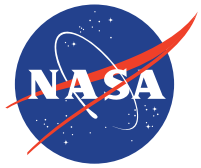
Summary and Next Steps

Summary:

- Team is making excellent progress on coronagraph technology maturation

Next Steps:

- TRL-5 demonstration: 9/30/2015
- SRR/MDR: 6/1/2017
- Life-cycle cost: 6/1/2017
- TRL-6 demonstrations: 9/30/2017
- KDP-B: 10/2/2017



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